A

THESIS ON

Fabrication and Experimental Studies of a Hybrid Flat Plate Solar Collector for Heating Pool Water

A Report Submitted In Partial Fulfillment of the Requirements for the Degree Of

Bachelor of Technology (Chemical Engineering)

Submitted by

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CERTIFICATE

This is to certify that the thesis entitled, **“Fabrication & Experimental Studies of a Hybrid Flat Plate Solar Collector for Heating Pool Water**” submitted by Anshuman Parida in partial fulfillments for the requirements for the award of Bachelor of Technology Degree in Chemical Engineering at National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance. To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

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ABSTRACT

Warm water in swimming pool is more of a necessity than comfort in places where temperature drops down below 25°C during winter. So pool water heaters are used extensively at places like Hotels, Hospitals, and Clubs etc. to bring the water temperature to a comfort level. But conventional pool water heaters require a lot of energy (electrical/fossil fuel energy) to run. Laws have been enforced in many countries which restrict the use of direct electricity to heat pool water.

This project report gives a detailed outline of the fabrication procedure of a flat plate solar thermal collector, built out of locally available materials. The report also contains the experimentation work carried out with the Collector model to determine its efficiency and optimum parameters. A brief solar surveying work was carried out during the project which has been explained. Finally, a feasible and economic heating system design is proposed which takes into account the temperature data of the water and air collected from **NIT Rourkela** swimming pool and the qualitative aspects of the fabricated flat plate solar collector.

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Nomenclature

SWH- Solar water heater

T_w - Water temperature

T_a - Air temperature

ΔT – Change in temperature

Q- Heat absorbed/dissipated

C_p – Specific heat

I.D – Internal diameter

O.D – Outer diameter

Q_{heater} –Heat absorbed by the solar heater

Q_{solar} - Heat dissipated by the sun

W_{heater} – Power output of solar heater

W_{solar} – Power output of Sun (Solar Power)

CHAPTER-1

INTRODUCTION

1. INTRODUCTION

1.1 Importance of the project

National Institute of Technology, Rourkela bearing (22.2 N, 84.9 E) although falls in the torrid climatic zone of earth, experiences a chilly winter, during the months of December and January, when the temperature dips to as low as 10°C. The institute has a big swimming pool (50m X 22m), which has to be made usable during these winter months to extend the swimming season. So it demands a water heating system that can bring the water to a comfortable temperature for public use.

1.2 Solar power in India

Energy resources are getting depleted day by day at a very alarming rate. So continuous research is going on around the world to harness energy from other renewable sources. While we think of the word "Renewable" the very first thing that comes to our mind is "Solar". With about 300 clear, sunny days in a year, India receives about 5 Petawatt-hours per year (PWh/year) (i.e; 5 trillion Kwhr/day). The daily average solar energy incident over India varies from 4 to 7 kWh/m^2 with about 1500–2000 sunshine hours per year), which is far more than current total energy consumption. For example, assuming if losses are minimized and processes optimized with better ideas and better technology, solar energy has enough potential to cater to the needs of modern man.Open-air swimming pools have been heated by solar energy for decades and the related technology is well established. However, this application of solar thermal energy has still room for improvement. The size of the absorber field of the solar system is usually calculated from a ratio given by experience between absorber surface and swimming pool surface.

1.3 Solar thermal collectors

A lot of work has already been done on building designs to heat pool water using solar collectors. Solar collectors generally fall into two broad categories: concentrating type and non-concentrating type. The concentrating type collectors usually employ parabolic/concave mirrors/reflectors to concentrate the total solar energy incident on the collector surface. So the collector surface is usually very wide and the temperature achieved is very high. For applications like heating pool water non concentrating type collectors are usually preferred. Flat plate collectors and evacuated tube collectors are the two most widely used non concentrating type of collectors. Flat plate collectors are the primitive type of collectors which are simple to fabricate and have very less maintenance cost. Evacuated tube collector technology is pretty young and is good for places which receive very less sunshine or have low ambient temperatures.

Flat plate solar collectors rely on offering a large surface area and are best to heat up pool water in places like that of India, which receives abundant sunlight throughout the year. Studies have shown that, even though heat losses in flat plate solar collectors is high, good designs based on heat transfer technology can give better results when compared with evacuated tube collectors.

The hybrid design solar collector that we have developed and fabricated as a part of the project, uses flat plate collector technology and concentrating type collector technology as well. All the experimentation on the collector has been done while keeping the collector unglazed (without a glass covering) & the results are satisfactory.

CHAPTER 2

LITERATURE REVIEW

2.1 Collectors used in modern heating systems

Solar thermal collectors capture and retain heat from the sun and then transfer this heat to a liquid. Two important physical principles that govern the technology of solar thermal collectors are [1]:

- Any hot object ultimately returns to a thermal equilibrium with its environment, due to heat losses from the hot object. The processes that result in this heat loss are conduction, convection and radiation. The efficiency of the solar thermal collector is directly related to the heat losses from the collector surface (efficiency being defined as the proportion of heat energy that can be retained for a predefined period of time). Within the context of a solar collector, convection and radiation are the most important sources of heat losses. Thermal insulation is used just to slow down the heat loss from a hot object to its environment.
- Heat is lost more rapidly if the temperature difference between the hot object and its environment is more. Heat losses are predominantly governed by the thermal gradient between the temperature of the collector surface and the ambient temperature. Conduction, convection as well as radiation occur more rapidly over large thermal surface gradients.

The simplest approach for solar heating of water is to simply mount a metal tank filled with water in a sunny place. The heat from the sun would then heat the metal tank and the water inside too. Indeed, this was how the very first SWH systems worked more than a century ago

However, this setup would be highly inefficient due to an oversight of the equilibrium effect, above: once when the tank and water has started to gain up heat, the heat gained would be lost back to the environment, ultimately until the water in the tank would be equal to the ambient temperature. The challenge is therefore to limit the heat losses from the tank, thus delaying the time until thermal equilibrium is attained.

2.2 Types of Collectors

a) **ICS or batch collectors**

These reduce heat losses by placing the water tank in a thermally insulated box. This is achieved by enclosing the water tank in a box with glass top that allows heat from the sun to reach the water tank; however the other walls of the box are thermally insulated, thus reducing convection as well as radiation to the environment. In addition to it, the box can also have a reflective surface on the inside. This reflects the heat lost from the tank back towards the tank. In a simple way one could consider an ICS solar water heater as a water tank that has been enclosed in a type of 'oven' that retains heat from the sun as well as heat of the water inside the tank. Using a box does not eliminate heat losses from the tank to the environment, but it largely reduces these losses. This is because; ICS collectors have a characteristic that strongly limits the efficiency of the collector: a very small surface-to-volume ratio. Since the amount of heat that a tank can absorb from the sun is largely dependent on the surface area of the tank directly exposed to the sun, it follows that a small surface area would limit the degree to which the water can be heated by the sun. Cylindrical objects such as the tank in an ICS collector inherently have a small surface-to-volume ratio and the most modern collectors attempt to increase this ratio for efficient warming of the water in the tank.

Flat plate collectors

These are an extension of the basic idea i.e.; to place a collector in an 'oven'-like box with glass in the direction of the Sun. Most flat plate collectors have two horizontal pipes at the top and bottom, called headers, and many smaller vertical pipes connecting them, called risers. The risers are welded (or similarly connected) to thin absorber fins. Heat-transfer fluids (water or water/antifreeze mix) is pumped from the hot water storage tank (direct system) or heat exchanger (indirect system) into the collectors' bottom header, and it travels upward in the risers, collecting the heat from the absorber fins, and then exits the collector out of the top header. Serpentine flat plate collectors differ slightly from this "harp" design, and instead use a single pipe that travels up and down the collector. However, since they cannot be properly drained out of water, serpentine flat plate collectors cannot be used in drain back systems.

The type of glass used in flat plate collectors are almost always low-iron, tempered glass. Being tempered, the glass can withstand significant hail without breaking, which is one of the reasons that flat-plate collectors are considered to be the most durable collector type.

Unglazed or formed collectors

These are similar to flat-plate collectors, except that they are not thermally insulated nor are they physically protected by a glass panel. Consequently these types of collectors are much less efficient for domestic water heating. For pool heating applications, however, the water being heated is very often colder than the ambient roof temperature, at which point the lack of thermal insulation allows an additional heat to be drawn from the surrounding environment.

Evacuated tube collectors (ETC)

These are a way in which heat loss to the environment, inherent in flat plates, has been reduced. Since heat loss due to convection cannot cross a vacuum, it forms an efficient isolation mechanism to keep heat inside the collector pipes. As two flat sheets of glass are normally not strong enough to withstand a vacuum, the vacuum is rather created between the two concentric tubes. Typically, the water piping in an ETC is therefore surrounded by two concentric tubes of glass with a vacuum in between that admits heat from the sun (to heat the pipe) but which limits heat loss back to the environment. The inner tube is coated with a thermal absorbent material. Life of the vacuum varies from one collector to the collector, anywhere from 5 years to 15 years.

****

CHAPTER-3

SOLAR SURVEYING AND DATA COLLECTION

3.1: Solar surveying [3]

Before installation of any solar heating system, a brief solar surveying should be done at the project site, to ensure the site receives proper sunlight and there are no blockages in the horizon (example: trees, tall buildings etc.) that could block the sun.

For the purpose of surveying we need an inclinometer [2], a compass and a Sunchart. An inclinometer/clinometer gives the inclination of an object/tree in the distant horizon. For the purpose of our work, a handmade inclinometer was used, which consisted of a cardboard sheet with a figure of a reverse protractor with marked angles glued to it. The center of the cardboard protractor has a hole through which a load is suspended. The viewer observes the object along the line sight line and the angle that the suspended load makes with the 0° mark, gives the inclination of the object.

Simultaneously the azimuth angle is to be measured for the object. The azimuth angle is nothing but the angle that the object makes with the south direction in the horizontal plane. It can be easily found out using a compass. Thus for each object in the horizon the azimuth angle and the inclination angle was noted down.

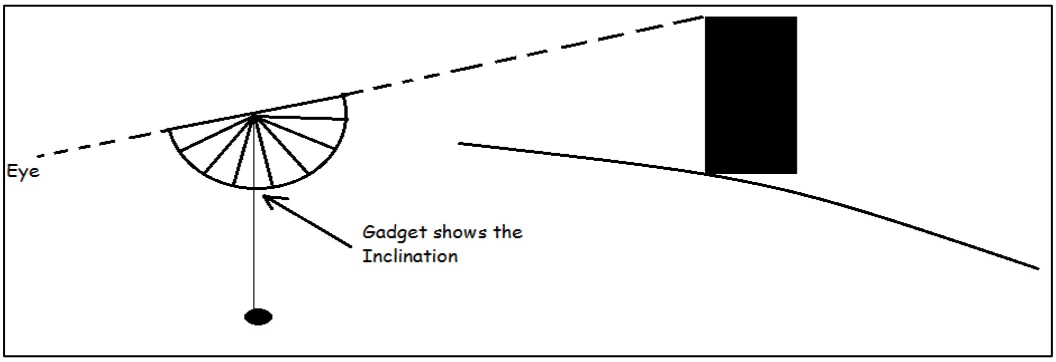

Figure 3.1 Measuring inclination with handmade inclinometer

3.2 Sunchart [4]

The next step in the solar surveying is plotting the points on a sunchart. A sunchart is a graph of the ecliptic of the sun through the sky throughout the year at particular latitude. Suncharts are available for free on websites. One such sunchart was downloaded from the site of University of Oregon, and the points obtained were plotted on the graph. The plot showed that our project site had a very few obstructions and the site received clear sunlight in-between 7:45 A: M to 4:45 P: M.

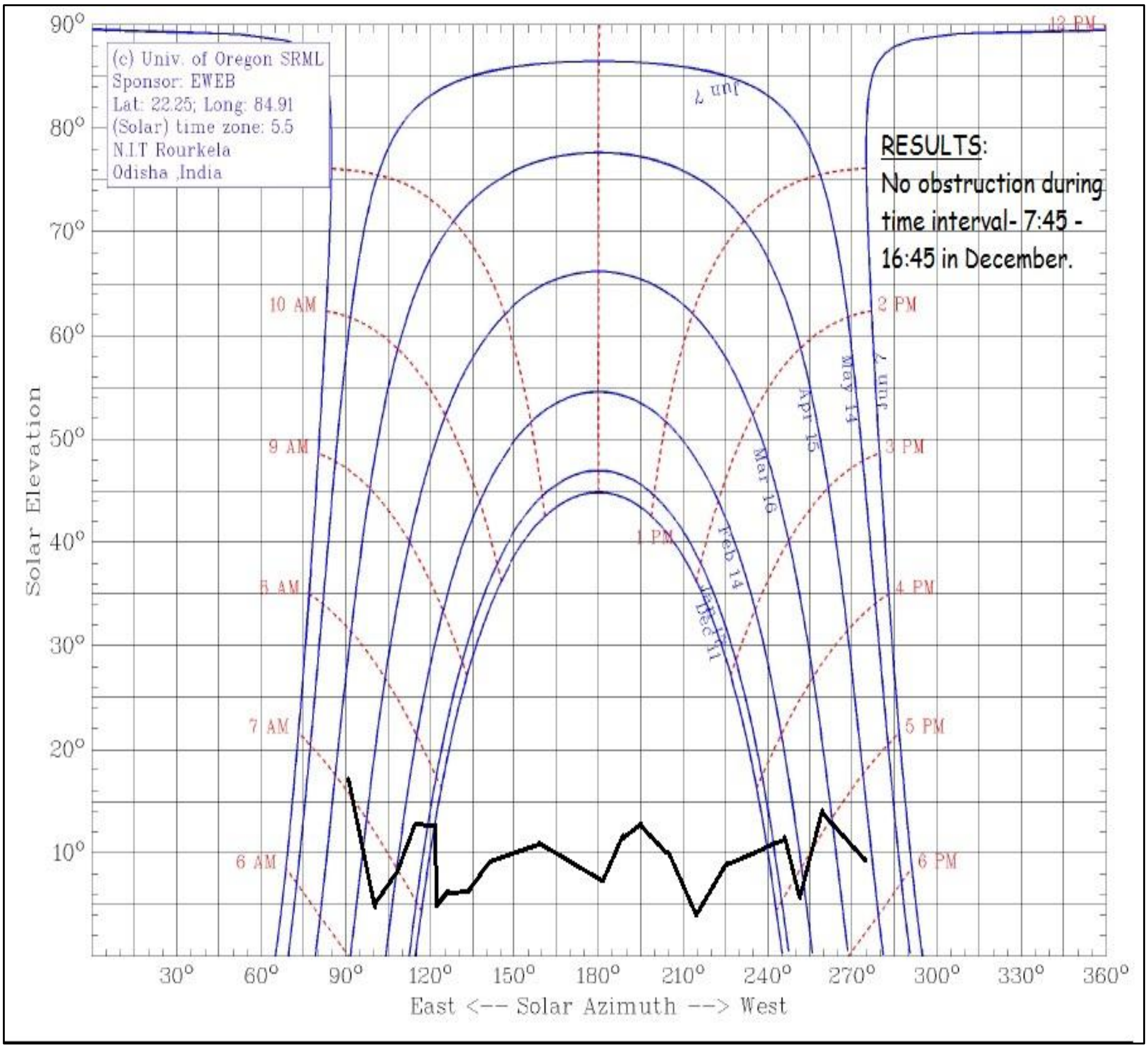

Figure 3.2 Line showing the inclination of horizon objects around the pool on Sunchart

3.3 The collector's orientation

For the best performance collectors are always placed at a 45° inclination with the ground. Collectors cannot face east/west direction, as the problems of shading would occur in the evening and morning hours. During winter the sun's path in the sky goes more toward the South Pole. So for using the sun's rays to the maximum limit we have to make the collectors face south direction. We used software: - **Google Sketchup** to confirm the fact that collectors facing south direction during winter months in India would never experience shade at any time of the day.

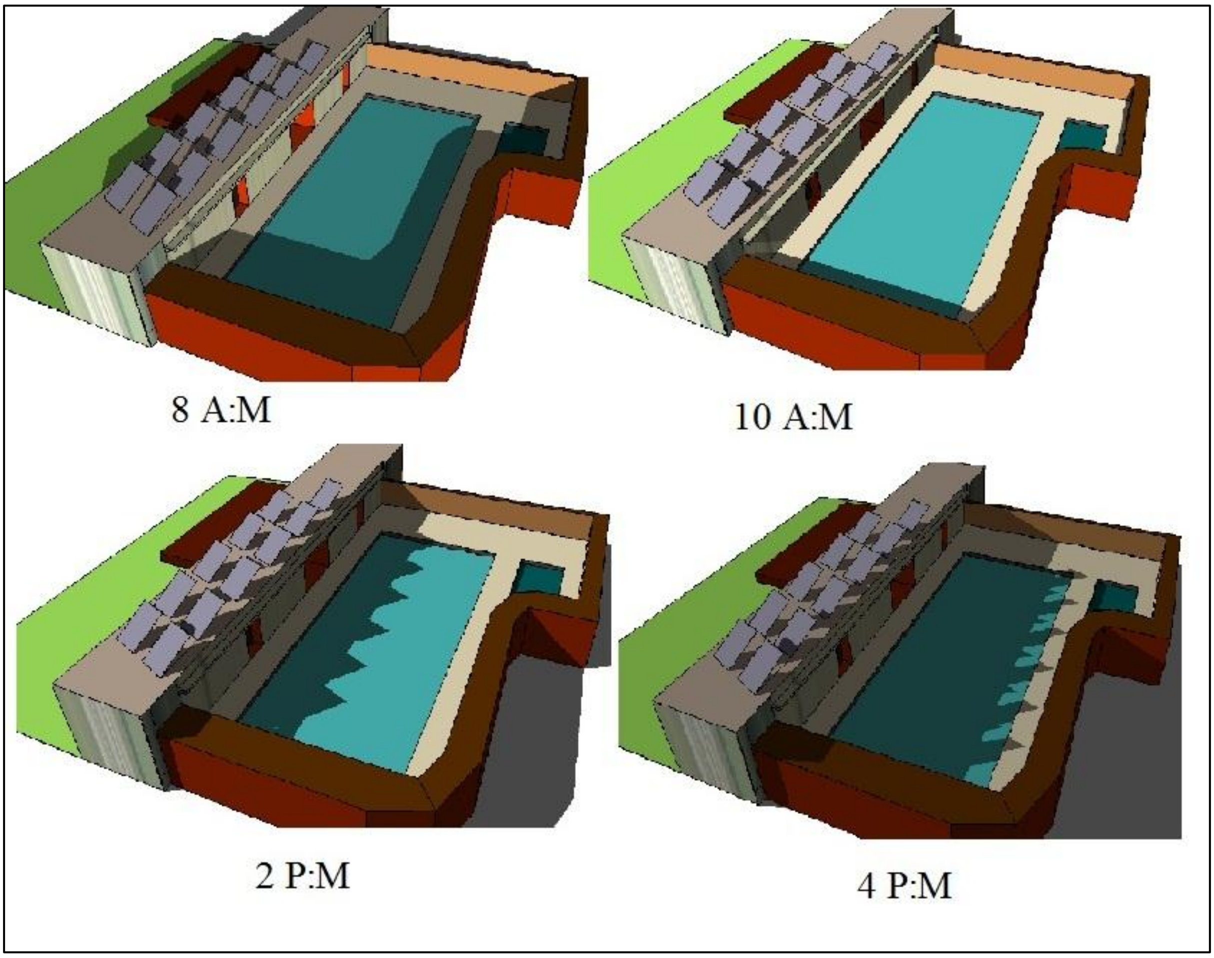

Figure 3.3 Google Sketchup Model:-Shadowing at different time intervals on a particular day in December month at NIT Rourkela with collectors facing South direction.

3.4 The basic data of NIT Rourkela swimming pool

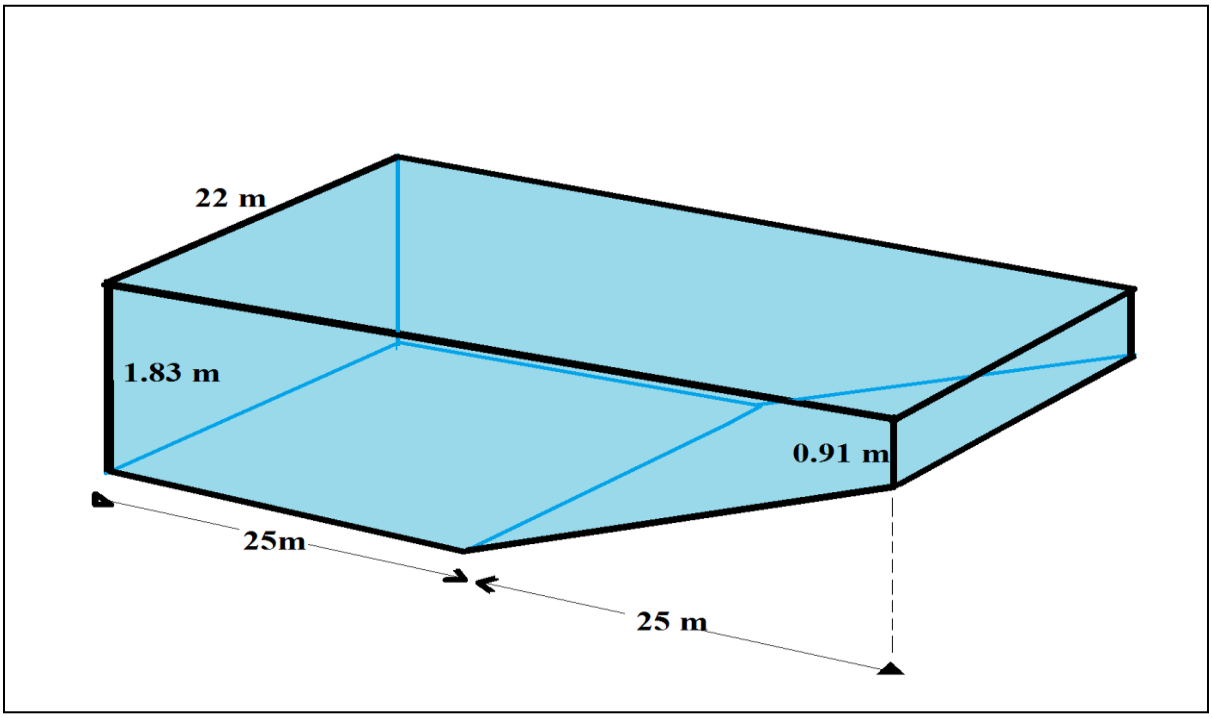

Figure 3.4 swimming pool in NIT Rourkela

Dimension:

Length: 50 meters

Breadth: 22 meters

Depth: 1.83 meters for half of the length & then decreases to 0.91 meters linearly as we move towards the shallow end.

Net volume of the water in pool (when completely filled):

(22 x 25 x 1.83) + (0.5 x 22 x 25 x (1.83+0.91)) = **1760 meter cube**.

3.5 Water flow system in the pool

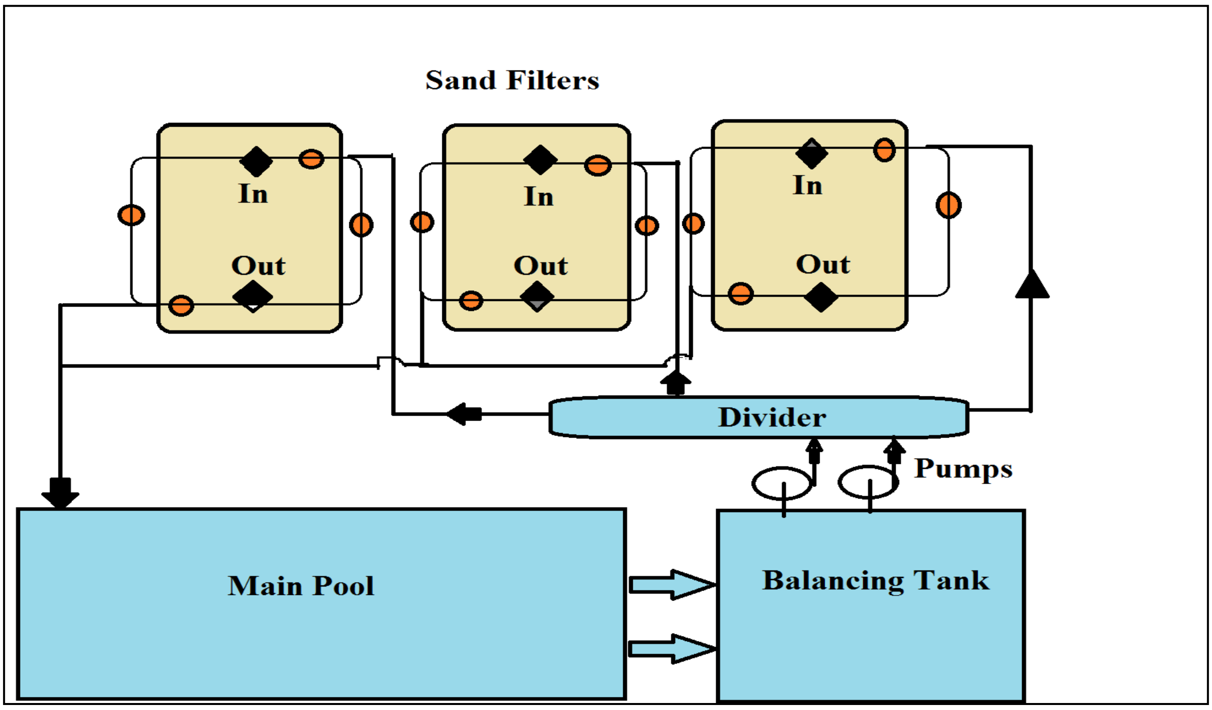

Figure 3.5 water flow system in pool

Specifications of the Filters & Pumps Used:

- Filters: 3 Fiber Bodied Sand Filters

  Capacity: 5000 liters/sec

  Filtration Area: 314 meter square

  Backwash Flow rate: 35 liters/sec

- Pumps: 4 Centrifugal Pumps

  Power: - 7.5 Hp, Class- B, Speed: - 2900 RPM

  Discharge: 140 meter cube/ hr = (2300 lpm)

3.6 Water and air temperature data

Institute Swimming Pool, Water & Air Temperature														(Month of November 2011)
Time:	6:00		6:40		7:30		9:00		12:00		16:00		17:30	
Date:	Water	Air	Water	Air	Water	Air	Water	Air	Water	Air	Water	Air	Water	Air
2	25	21	25	22	24	23	25	30	26	31	25	22	24	24
3	25	22	24	22	23	22	25	29	25	32	24	21	25	22
4	27	25	25	23	24	23	26	28	27	32	26	22	26	24
5	24	23	24	21	27	26	25	27	28	31	25	21	28	26
6	25	22	24	21	26	24	26	28	29	30	25	22	25	21
7	25	21	24	23	24	29	23	29	28	31	27	22	24	23
8	24	22	23	22	26	24	26	21	27	25	28	23	25	24
9	25	23	26	24	28	28	28	25	29	31	29	28	27	25
10	25	22	24	25	30	27	26	28	30	32				
11	24	21	26	24	26	24	27	25	29	31	30	31	25	24
12	25	22	27	23	25	23	27	26	30	28	28	30	28	26
13	27	23	28	22	24	22	26	24	32	30	27	25	28	28
14	26	25	27	25	28	24	30	28	31	30	28	29	30	31
15	27	25	27	26	28	27	30	28	30	32	27	25	27	25
16	27	26	27	27	26	27	28	26	30	31	28	27		
17	26	25	26	27	28	27	28	27	29	30	27	28		
18	27	25	25	26	28	27	29	27	32	35	27	25	29	27
19	27	26	28	27	28	26	30	31	30	30	28	26		
20	28	26	28	27	30	28	30	31	30	32	28	26		
21	28	26	28	26	30	26	30	31	30	32	28	26		
22	25	23	26	24	27	26	29	28	30	31	28	30		
23	25	23	26	24	25	26	28	27	31	32	27	29		
24	25	24	26	25	28	29	30	31	30	29	26	24		
25	24	26	27	25	26	25	28	27	30	32	28	26		
26	27	29	28	26	30	31	29	28			29	30		
27	26	28	28	27	28	27	30	31	32	35	28	30		
*Temperatures in Degree Celsius														

Table 3.1: temperature data of air and water in pool

Time:	6:00	6:40	7:30	9:00	12:00	16:00	17:30
Avg Temp of Water:	25.75	26	26.8	27.65	29.4	27.25	26.5
Avg Temp of Air:	24	24.4	25.8	27.7	31	25.9	25

Table 3.2: Average Temperature of Water & Air for the month of November 2011

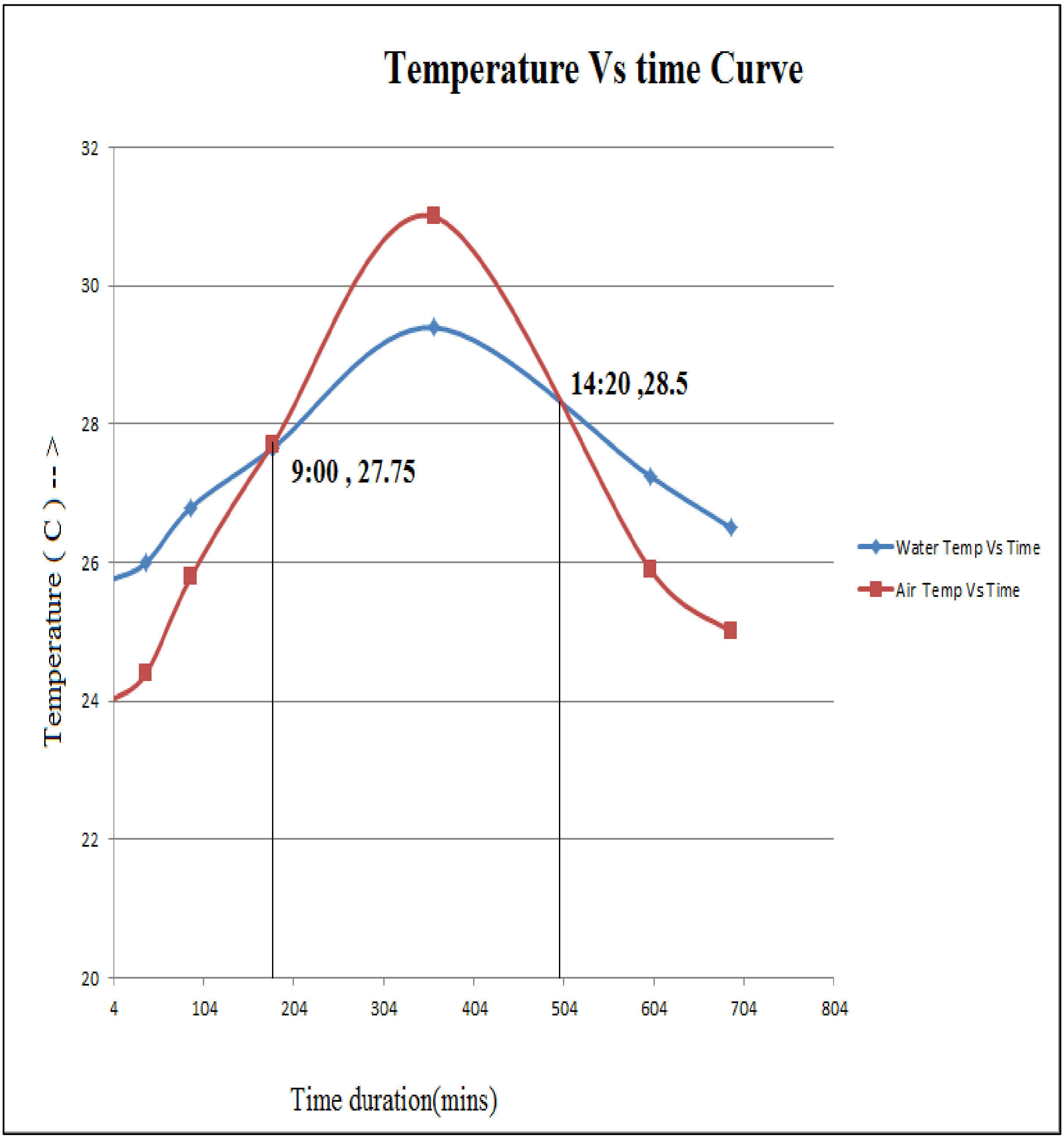

Figure 3.6: Average temperature of water and air Vs time curve

3.7 Inference obtained from the Curves:

Two points were observed on the graphical plot, where we observed a temperature cross. The first temperature cross occurred at 9:00 am and the second occurred at about 2:20 pm. The duration between the crosses is 5hours and 20 minutes.

The data is taken for the month of November but a similar trend is expected for the months of December and January (The winter months in Rourkela).

The water and air temperatures are found to be a function of time of 4^{th} order.

Water temperature curve: $\mathbf{Tw = 2E\text{-}10t^4 - 3E\text{-}07t^3 + 9E\text{-}05t^2 + 0.003t + 25.789}$ {1}

Air temperature curve: $\mathbf{Ta = 5E\text{-}10t^4 - 7E\text{-}07t^3 + 0.0002t^2 - 0.0003t + 24.093}$ {2}

Tw- Water temperature,

Ta- Air temperature,

t- Time elapsed (minutes) from 6:00 a: m

The 2 temperature crosses gives the minimum duration during which the pool water has to be heated in order to bring the water temperature at par with the ambient temperature thereby by making it comfortable for use.

Heat Load: If it’s needed to increase the pool temperature by 5 degree Celsius.

$\Delta T = 5\ °C$, $Q = m\ .C_p.\ \Delta T$ {3}

= 1760 x 1000 x 4182 x 5 = **37000 MJ**

Assuming Heating Period is **6 hours**. So power Input of the heat source is

= 37000/ (6 X 60 X 60) MW = **1.7 M Watts**

CHAPTER-4

FABRICATION

WORK

Solar thermal Collector has following basic things for fabrication:

- Outer Cabinet Box
- The Piping Network & Plumbing
- The fin/reflector fabrication

❖ 4.1 Outer Cabinet Box

The outer cabinet box of the solar thermal collector is fabricated out of waterproof Plywood.

The box has dimension: 1.22m X 0.61m X 0.10m

Flat Surface Area: 1.22X0.61 Sq. Meters.

Thickness of Plywood: 6 mm

Dimension of the Plywood Planks required during the fabrication:

Units:	Size:	Thickness:
1	1.22m X 0.61m	6 mm
2	1.22m X 0.10m	6 mm
2	0.61m X 0.10m	6 mm

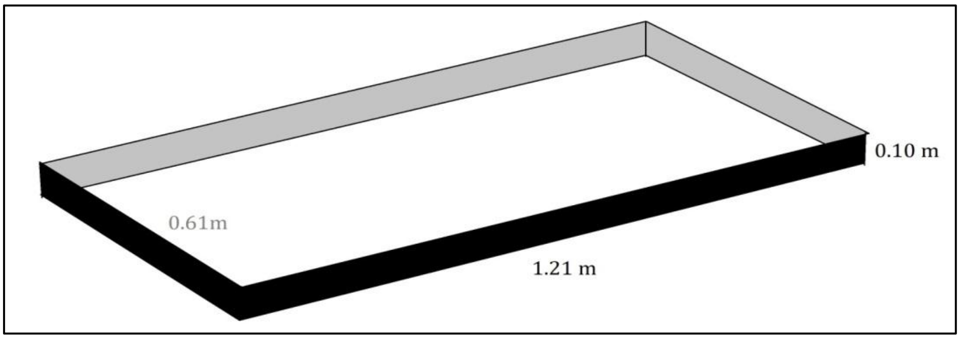

Figure 4.1:Wooden Outer cabinet

The planks were attached with the help of Steel Nails (2.3 cm) & the Gaps were sealed using Glue and Sealing Materials. The box was cut at the required places to allow Pipes for Inlets and Outlets.

❖ 4.2 Piping Network & Plumbing

4.21 Piping Network

Aluminum pipes were used for the purpose of Heating.

Dimension of the Pipes used (As per market availability):

Outer diameter: 1.8 cm Inner diameter: 1.6 cm

Thickness: 1mm

Number of Pipes used: 8

Length of the pipes: 115 cm (Keeping 3 cm clearance along the length from the outer Box on both sides)

Minimum Spacing between Adjacent Pipes

The minimum space between adjacent pipes should be kept 4R, where R –Radius of the Pipe. The basic laws of Light and Shadowing Supports the fact.

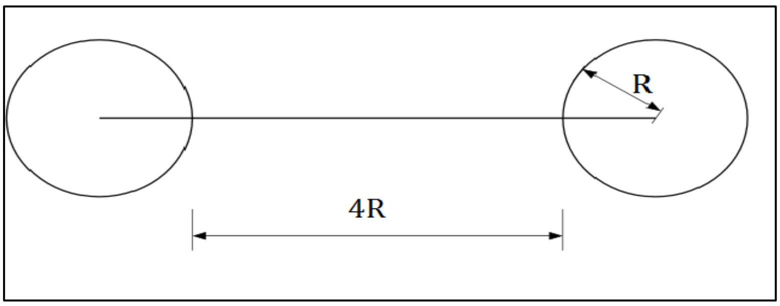

Figure 4.2: Spacing between pipes

If pipes are spaced at 4R distance from each other, the possibility of one pipe overshadowing another pipe during any time of the day is eliminated. So the active distance between to adjacent pipes becomes 6R.

6R distance is equivalent to = 6 X 0.9 = 5.40 cm (Minimum Spacing)

Now total number of pipes that can be spread out over the breadth of the Box

= (Box breadth/ Pipe spacing)

ie; 61/5.4 = 11.2 Pipes

But for uniformity and Keeping additional Safety clearances in mind, we take 8 pipes for Fluid Flow. We then assumed the Spacing between pipes to be 6.5 cm & then carryout the necessary Calculations. Then we have 7 inter pipe spacing of 6.5 cm each making the length up to 45.5 cm & so we divide the rest area into 2. ie; of 7.5 cms each.

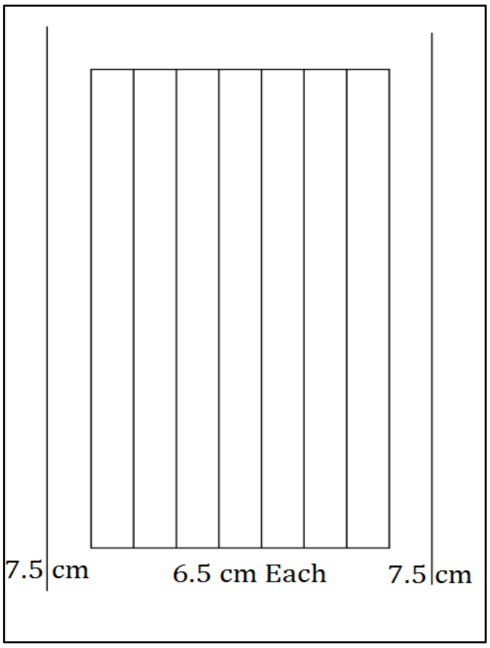

Figure 4.3: The piping network and spacing

4.22 Plumbing

- Header
- Follower
- Distributors

The model has a network of 8 pipes (distributors) all connected to a header & then with a Follower (Collector) at the bottom. The header is fabricated out of a series of PVC Tees, each connected to each other with the help of Aluminum Pipes.

Dimension:

I.D = 1.8 cm

O.D = 2 cm

The pipes in between the Tees are wrapped with Teflon tapes for better fitting and inserted into the Tees.The Gaps in between is sealed properly with Glue & Waterproof Adhesives.

The 8 pipes (Distributors) are then inserted into the 3rd opening of the Tee with proper Sealing. The follower is made out of Heat resistant PVC Pipe. The PVC pipe has I.D = 8 cm. 8 bores of diameter = 2 cm, are drilled along the length of the Pipe, at proper spacing, so as to accommodate all the 8 pipes, without any deformity/twisting. Then the 8 distributor pipes are inserted into it, & the gaps are properly sealed to avoid leakages.

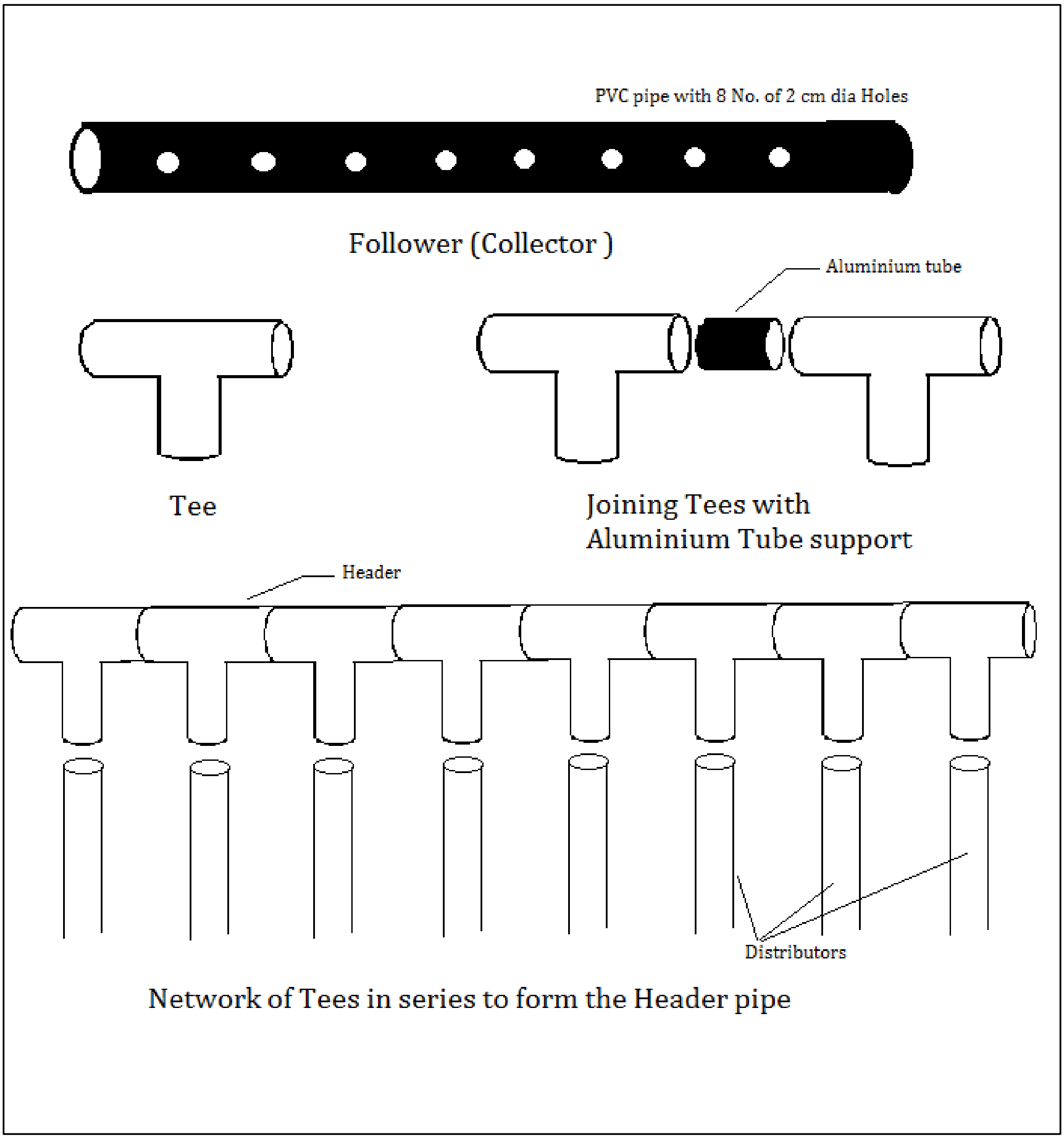

Figure 4.4:Plumbing and piping

❖ 4.3 Fin/Reflector Design

The innovativeness in the Solar Thermal Collector described in this thesis, is in its unique fin design. The fin design described below improves the Heat Conduction area, while concentrating the Sunlight on to the pipes as well. The tubes containing water are wrapped by metal sheet, and then curved at a fixed curvature with the focus at the Pipe centre.The space between two adjacent tubes has the aluminum sheets in a pattern as shown below.

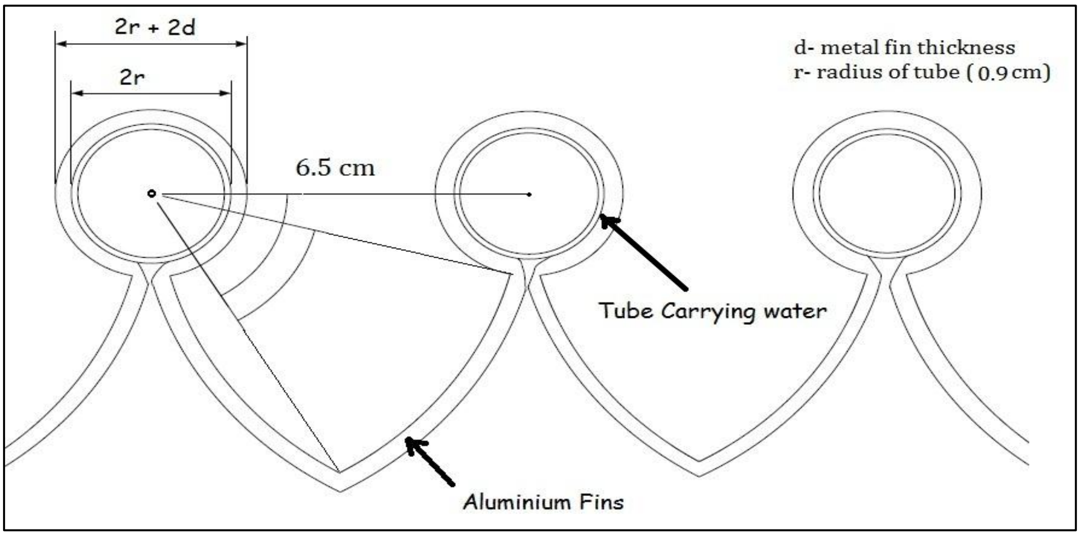

Figure 4.5 Cross-section of fin pipe assembly

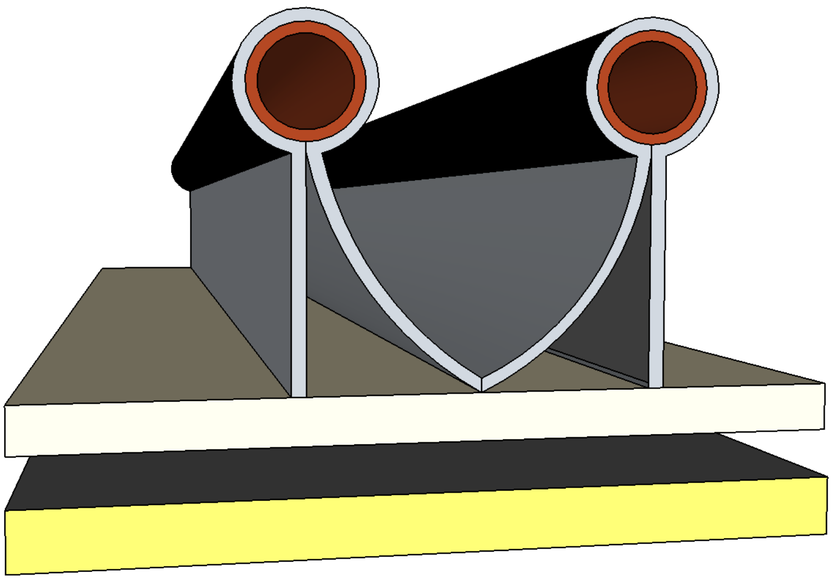

Figure 4.6 :Google sketchup Fin model -1

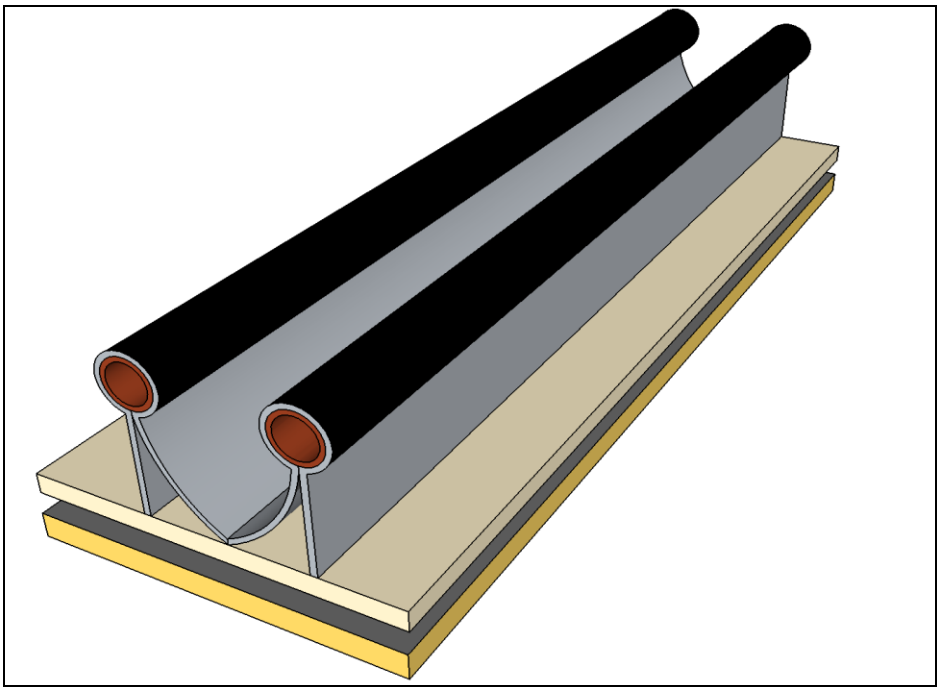

Figure 4.7 Google sketchup Fin model -2

4.4 Key Features in the Fin design:

- Aluminum fins are wrapped all over the Tube surface very rigidly.
- The fins cover the interspace between the adjacent tubes increasing surface area for Heat Collection.
- The fins are in a definite geometry. ie; They have a fixed curvature having their focus at the pipe center, so as to reflect the unabsorbed light rays on to the Tubes.

  So, if say absorptivity of the aluminum sheet is 50%, then it conducts the 50% heat to the pipes by means of conduction ,rest 50% heat in form of light rays are concentrated on to the pipes. So ideally the heat losses are assumed to be zero.

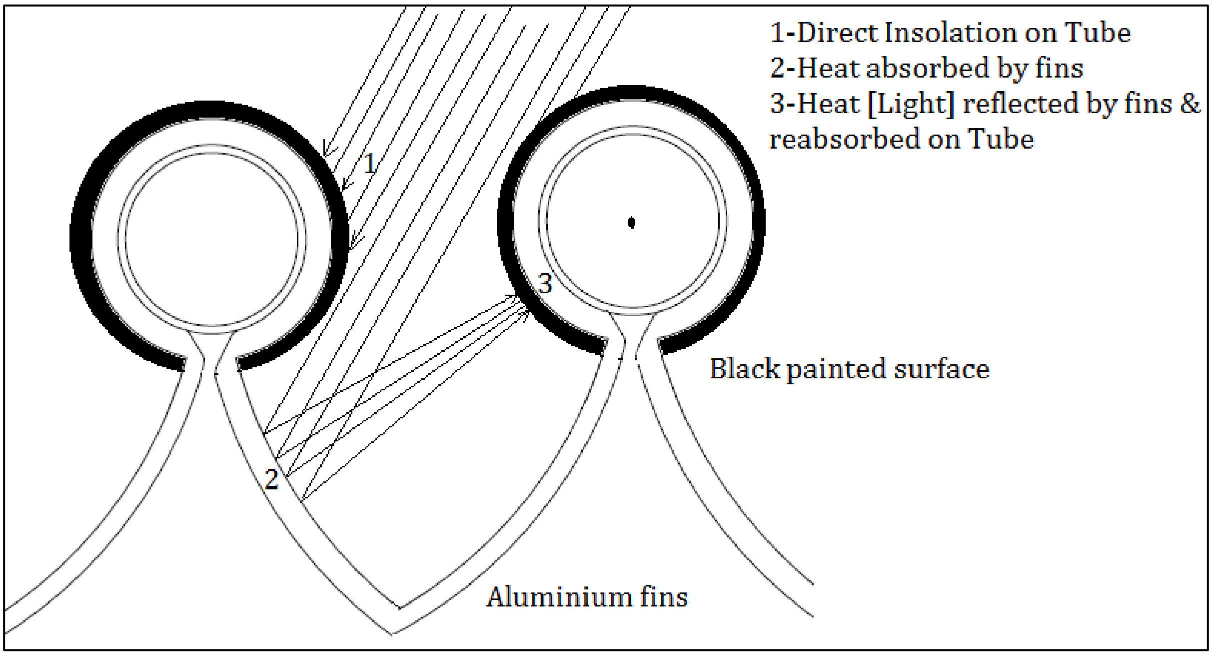

Figure 4.8: Sun's rays absorption on Fins

Forms of Heat Transfer from Sun's Rays

1- Direct Insolation of Sun's Rays on the Black painted Tube Surface.
2- The direct Conduction of Heat on the Metal Fins from direct Sunlight.
3- Heat in the form of sunrays reflected from the Glossy metal Surface on to the tube.

4.5 Fin Fabrication

For fabricating the Aluminum fins the following steps were followed:

- The aluminum sheet was cut using scissors at the desired markings
- Then the pipe was then kept on the Sheet at the desired spot & clamped.
- The sheet was then carefully & neatly rolled over the pipe and bent at the right places by applying pressure.
- Holes were drilled at the ends of the sheet, through which wires were put to fasten the sheet to the pipe.
- Then the Fins were curved at the required angle so as to act as solar concentrators.

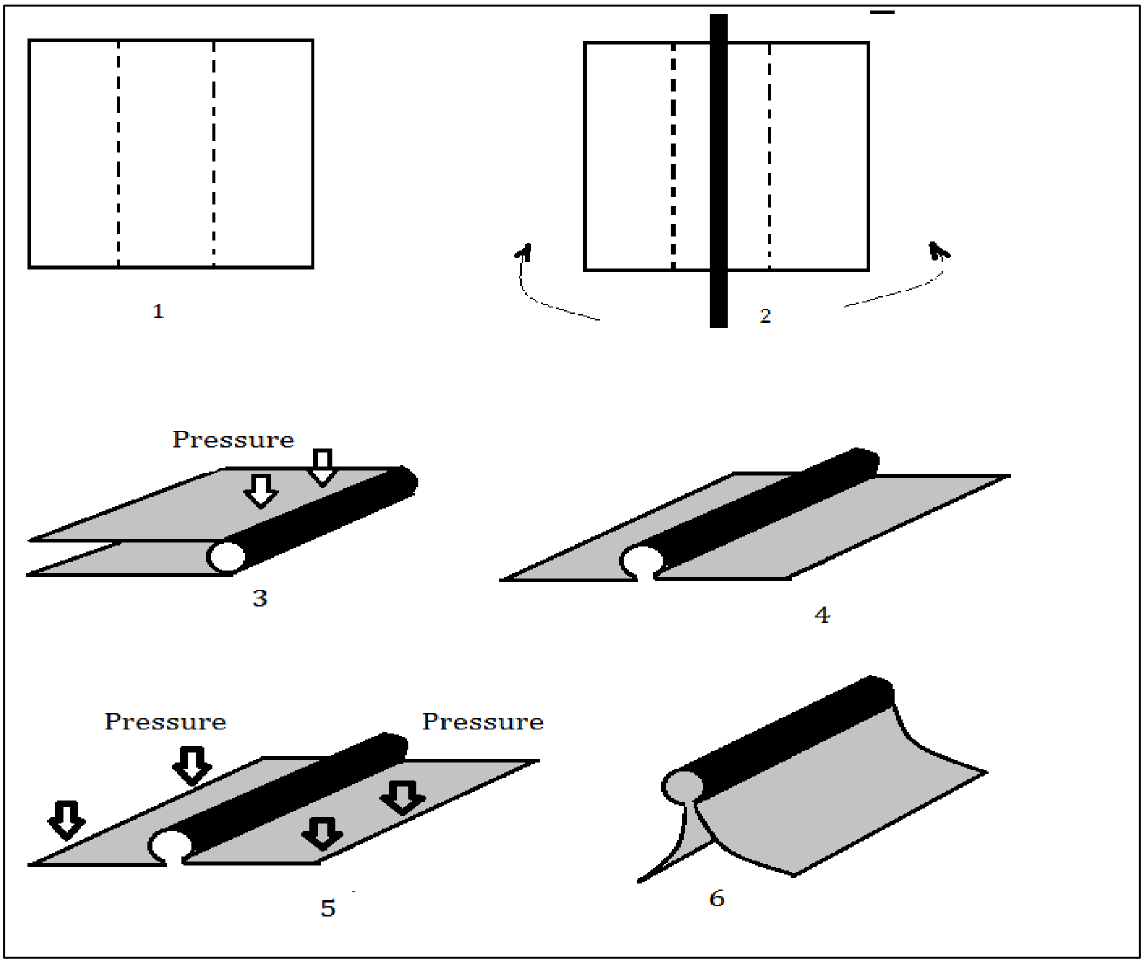

Figure 4.9: Fin fabrication

4.6 Finishing Work & the Final Model

The outer cabinet box was painted pitch black. The piping network was then spread in the box & the Inlet and outlet pipes were taken out at the desired spots. The whole piping network was then supported on wooden stands attached to the cabinet body and then clamped securely to the box.

Then the fins were placed on the pipes very carefully, so as to minimize the air gap between the fins and the tubes. Fastening wires were used at the desired spots to make the model robust. Araldite Glue & Adhesives were used wherever sealing was essential, to reduce heat & material losses.

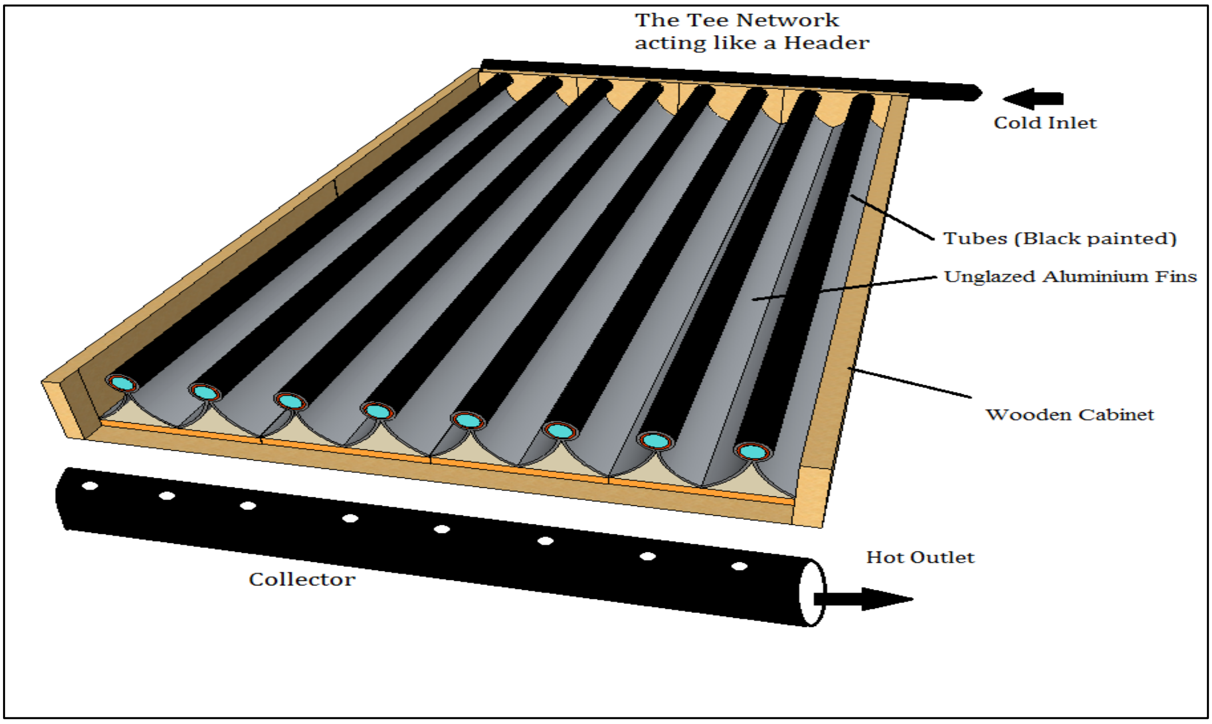

Figure 4.10: Final Layout on Google sketchup software

4.7 Geometrical details of the Model

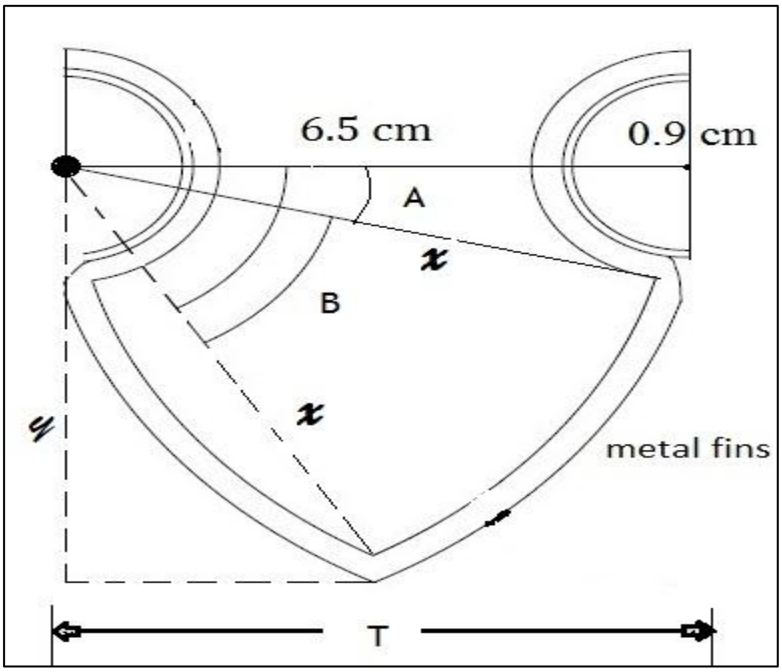

Figure 4.11: Geometrical dimensions of fin

The above figure gives the cross-section of the solar thermal collector. T is the time period, after which the pattern gets repeated.

So the model has 8 tubes so we expect 7 time periods and 2 half time periods. So all total there are 8 time period lengths of the shown pattern.

Calculation of X & Y:

$X^2 = 6.5^2 + R^2$ {Sides of a right angled triangle property}

R = 0.9 cm

X = 6.56 cm

$Y^2 = X^2 - (6.5/2)^2$

So Y comes out to be = 5.7 cm

So height of the center of the Tubes from the cabinet base is kept 5.7 cm.

Calculation of angles A & B:

A+B = 60° [Geometrically designed, ie; the fins have a curvature with focus at the center of the tubes]

tan A = 0.9/6.5

$A = \tan^{-1}(0.9/6.5)$

$= 8°$

So, B = 52°

Calculations of Surface Areas Generated:

Total surface area generated (per unit length of 1cm) over a time period length, T

= 2* ((Area over the tubes) + (Area of the fin))

$= 2 * ((\pi * 0.9) + ((52/360) * 2 * \pi * 6.5))$

$= 17.44\ cm^2$

Now for 8 such time periods we have total area (per unit length of 1 cm) = 140 cm^2

So total Aluminum sheet required to cover the surface of collector = (140*100) cm^2

= **1.4 meter^2**

[Fins are provided for only 100 cm out of 1.21 meters total length, rest 21 cm is for clearance]

4.8 Facts about the design geometry:

- Aluminum Pipes used: 8 [Length: 115 cm,O.D =1.8 cm, I.D = 1.6 cm]
- Aluminum Sheet used: (140 cm X 100 cm) = 1.4 meter^2
- Total active surface area available = 1.4 meter^2
- Heater box area : (121cm X 61cm) =0.738 meter^2

CHAPTER-5

EXPERIMENTATION

Now to determine the efficiency of the solar collector fabricated, it is put to test under the Sun, while water circulating through it.

5.1 Experimental Setup

The experimental setup consists of:

- The fabricated SWH (Solar water heating System)
- Plastic water pipes
- A Pump with Bypass flow arrangement (0.5 Hp)
- Flow control valves (2no.s)
- Rota meter (0-20 lpm)
- An Insulated Water Storage Tank
- Cardboard Sheets & other Insulation materials.
- Steel/Wooden support for mounting the SWH
- Water & Power Supply
- Thermometer/ Temperature measuring equipment

5.2 Procedure

- The open garden place (without shade) was chosen for the experiment.
- The true South direction was determined with the help of compass & then the SWH was fixed properly on wooden/steel supports facing the South direction while making an angle of 45 degrees with the ground.
- The flow connections were made proper & the pump was switched on.
- The outlet temperature in the insulated box was measured at regular intervals of time, with different flow rates of water.

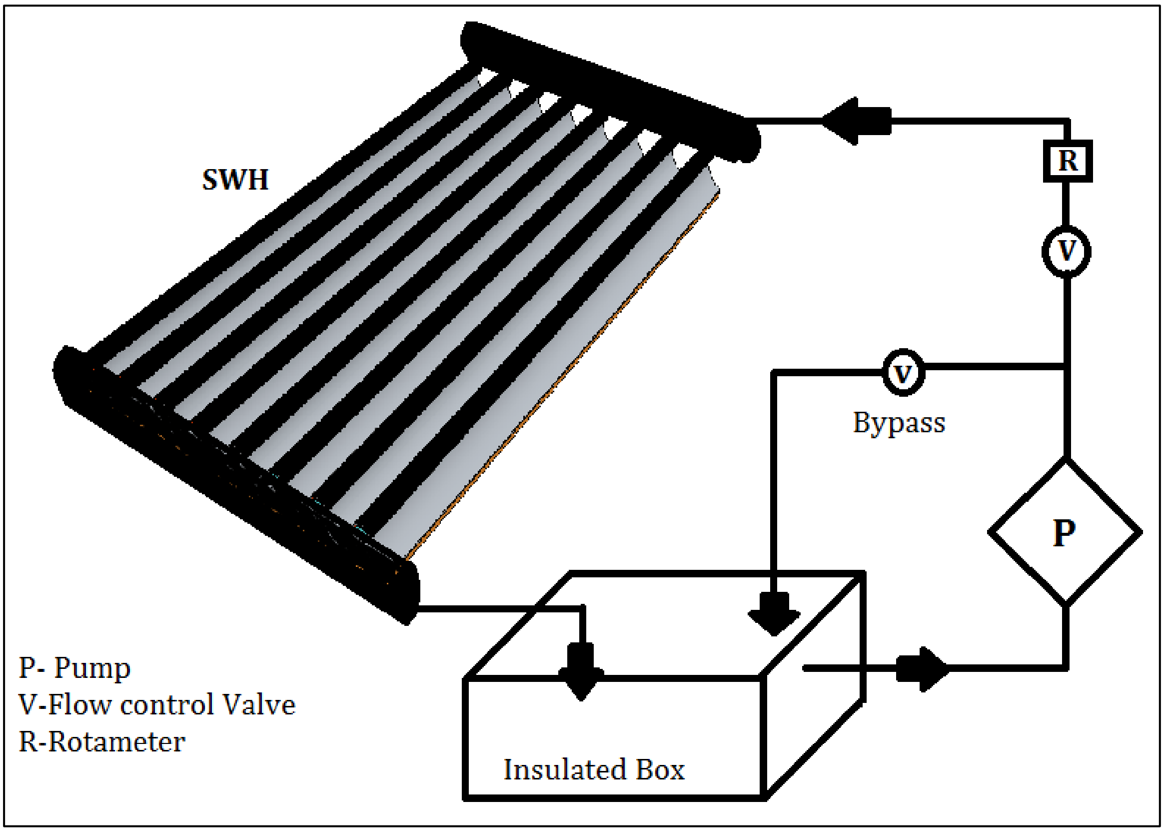

Figure 5.1: Experimental setup

Figure 5.2 Actual experimental setup

CHAPTER-6

RESULTS

AND

DISCUSSION

Water was allowed to flow through the SWH continuously by the help of the pump and the temperature of the water in the insulated tank was noted down at regular intervals of time.

6.1 Trial Run -1

Experiment conducted on: 7th May 2011

Ambient air temperature: 36°C

Volume of water in the tank = 26 liters

Flow rate of water = 6 lpm

Time of experiment: [3:30 p: m to 4:05 p: m]

Time duration (mins)	Temperature (°C)	Cumulative (ΔT/Δt)
0	34	
5	36	0.4
10	38	0.4
15	40	0.4
20	41	0.35
25	42	0.32
30	42	0.266666667
35	43	0.257142857
40	44	0.25
45	45	0.244444444
50	45	0.22
55	46	0.218181818
60	46	0.2
65	47	0.2
70	47	0.185714286
75	47	0.173333333
80	48	0.175
85	48	0.164705882
90	48	0.155555556
100	49	

Table 6.1 Temperature readings for trial-1

6.2 Calculation of collector efficiency (complete cycle)

The efficiency of the SWH is calculated for the trial-1 for the given period of heating time

Total duration of heating = 100 minutes

ΔT achieved = (49-34) = 15°C

Mass of water = 26 kg

C_p of water = 4187 J/kg°C

$\mathbf{Q_{heater}} = m*C_p*\Delta T$

= **1633 KJ**

$\mathbf{Wattage_{heater}}$ = Q/t

= **270 Watts**

Average solar power in India is 5 KW/meter^2 [5]

Surface area of the collector = 0.738 meter^2

So net solar power incident on collector surface = [5 * 0.738 * cos 45°]

= **2.61 KW**

{cos 45° gives the projection of the collector on the ground, as it is tilted at an angle of 45° with the horizontal surface }

So Efficiency of the collector = $[W_{heater}/W_{solar}] * 100$

= **10.34 %**

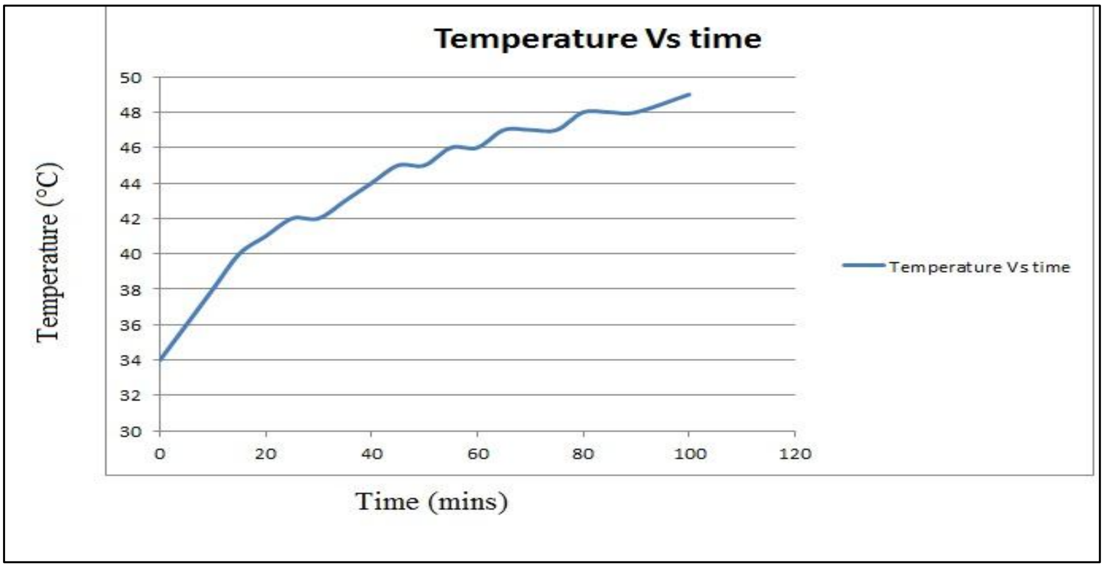

Figure 6.2: graph T Vs t trial run-1

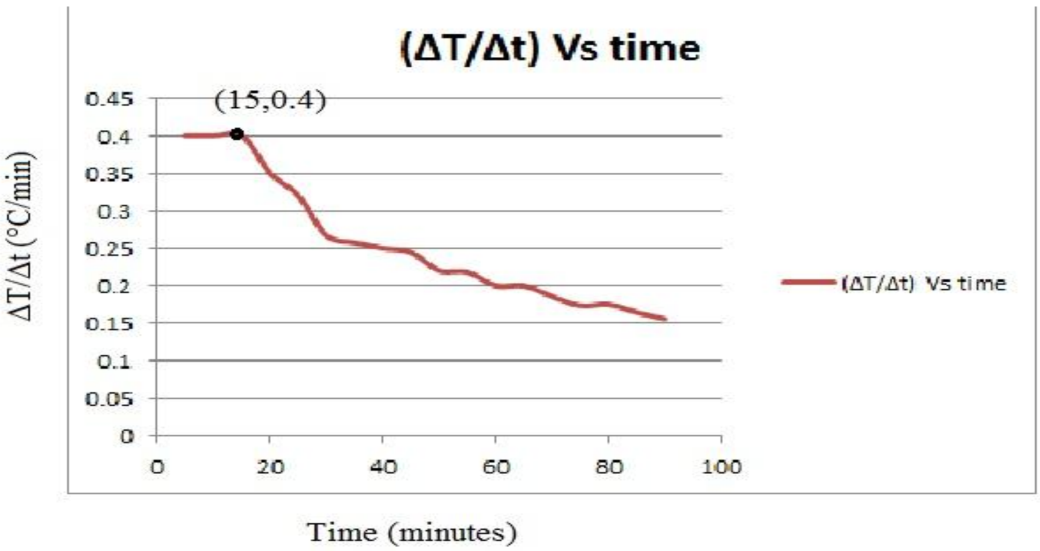

Figure 6.3:Graph ΔT/Δt Vs time trial-1

6.3 Calculation of efficiency for the first 15 minutes

The graph [Fig 6.3] shows that the $\Delta T/\Delta t$ is maximum and steady for the first 15 minutes. So the maximum efficiency of the collector comes if it is operated for this duration only.

ΔT is 6 degrees in 15 minutes.

Calculation efficiency in the same procedure we have

Wattage$_{heater}$ = ($m*C_p*\Delta T/\Delta t$)

= (26* 4187 * 6)/(15 * 60)

= 726 Watts

So efficiency = (72600/2610)

= **27.8 %**

So if the solar water heater is operated within this range of time, it is definitely going to work well and deliver a large amount of heat.

6.4 Trial run-2

During this run the flow rates were kept 5, 10 and 15 lpm respectively for 3 sets of observation and graphs plotted.

Experiment conducted on: 8th May 2011, Ambient air temperature = [33°C -37 °C]

a) Volume of water in tank = 25 liters

   Time of experiment: [11:00 a: m – 12:00 p: m]

   Flow rate: 5 lpm

TimeDuration(mins)	Temperature (°C)	Cumulative (ΔT/Δt)
0	34	
5	35.5	0.3
10	37	0.3
15	38.5	0.3
20	39.5	0.275
25	41	0.28
30	42	0.266666667
35	43	0.257142857
40	44	0.25
50	45	0.22
60	46	0.2

Table 6.2 Temperature readings trial -2(a)

b) Volume of water in tank = 28 liters

Time of experiment: [12:15 p: m – 1:40 p: m]

Flow rate: 10 lpm

TimeDuration(mins)	Temperature (°C)	Cumulative (ΔT/Δt)
0	34	
5	36	0.4
10	38	0.4
15	39.5	0.366666667
20	41	0.35
25	42	0.32
30	43	0.3
35	44	0.285714286
40	45	0.275
45	46	0.266666667
50	47	0.26
55	47.5	0.245454545
60	48	0.233333333
70	49	0.214285714
75	50	0.213333333
85	51	0.2

Table 6.3:Temperature readings trial 2(b)

c) Volume of water in tank = 28 liters

Time of experiment: [2:25 p: m – 3:35 p: m]

Flow rate: 15 lpm

TimeDuration(mins)	Temperature (°C)	Cumulative (ΔT/Δt)
0	34	
5	36	0.4
10	38	0.4
15	39.5	0.366666667
20	40.5	0.325
25	41.5	0.3
30	42.5	0.283333333
35	43.5	0.271428571
40	44.5	0.2625
45	45	0.244444444
50	46	0.24
55	46.5	0.227272727
60	47	0.216666667
70	48	0.2

Table 6.4:Temperature readings trial 2(c)

TimeDuration(mins)	Temperature (°C)	Efficiency of collector (%)
0	34	
5	36	27.8063857
10	38	27.8063857
15	39.5	25.48918689
20	41	24.33058748
25	42	22.24510856
30	43	20.85478927
35	44	19.86170407
40	45	19.11689017
45	46	18.53759046
50	47	18.0741507
55	47.5	17.0630094
60	48	16.22039166
70	49	14.89627805
75	50	14.83007237
85	51	13.90319285

Table 6.5 Efficiency factors for 10lpm flowrate

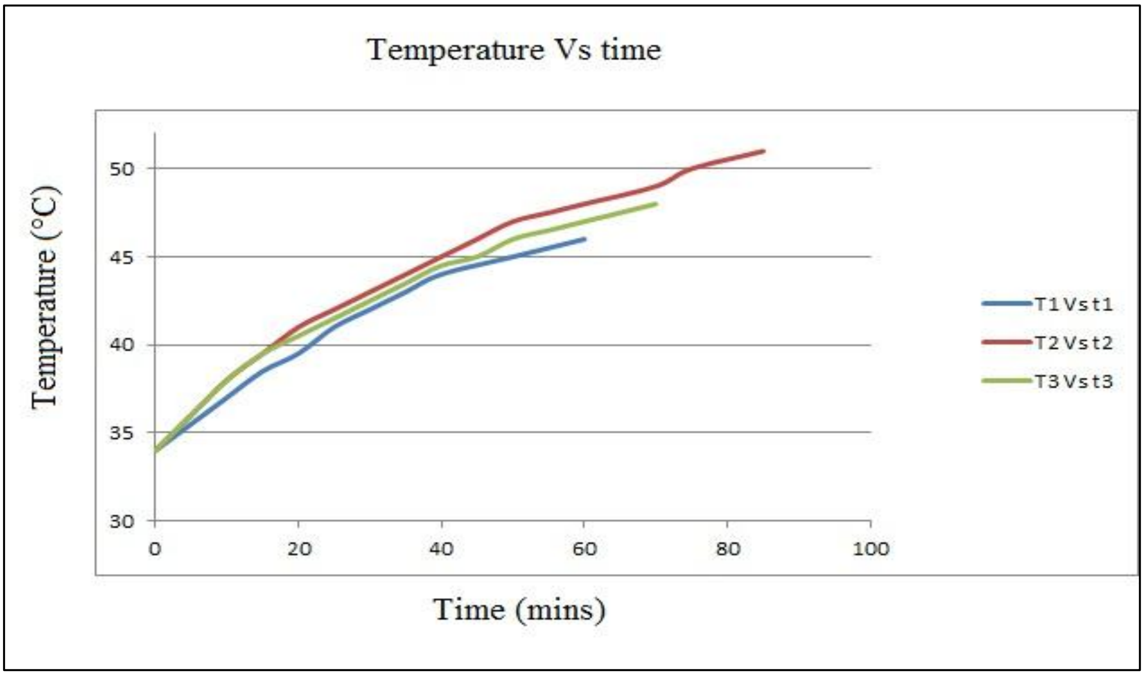

Figure 6.4 T Vs t for trial 2 with different flow rates

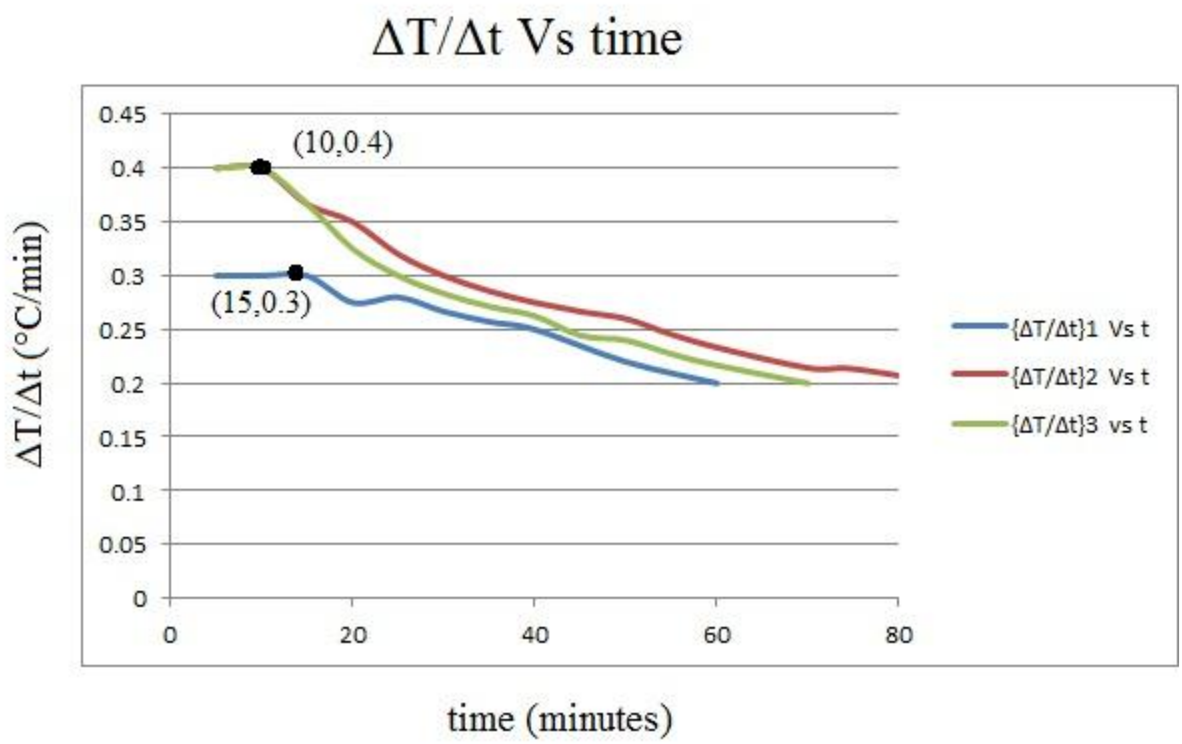

Figure 6.5 ΔT/Δt Vs t for trial-2 with different flow rates

6.5 Discussions

So the fabricated model was tested with different flow rates of water starting from 5lpm and ending with 15 lpm and the variation of collector efficiency with time was studied.

Efficiency of the collector is directly proportion to the $\Delta T/\Delta t$ ie; the rate of change of temperature per unit time. The following observations were noticed.

Trial -1

The above observations and graph [Fig 6.2] plots suggest that, with a batch feed of water to a solar water heater, the temperature of water goes on increasing with time until a saturation level, after which there is no significant change in the outlet temperature. It so occurred as the solar water heater fabricated had an upper limit after which heating is not possible. The temperature of water almost approaches the temperature of the metal fins and the tubes. For the trial 1 the upper limit came out to be 49°C.

It was also observed [Fig 6.3] that the rate of increase of temperature per unit time went on decreasing with time. It was because the temperature of water increases at a steady rate in the beginning but as time progresses saturation of temperature occurs and temperature rise is not significant.

$\Delta T/\Delta t$ was steady for **15** minutes at **0.4°/min** and it decreased with time. So the efficiency of the SWH is maximum within the 15 minutes and then later efficiency degrades.

Trial -2

The same procedure was applied in the 2nd trial but with 3 different water inlet flow rates to study the relationship between the water flow rate and the rate of heating. Graph [Fig 6.4] between temperature and time follows the same trend as in trial-1.With increase in flow rates of water the rate of increase of temperature per unit time increases as shown by the curves. The $\Delta T/\Delta t$ remains steady [Fig 6.5] for a period of time ie; 10 minutes for 10 and 15 lpm flow and 15 minutes for 5 lpm flow respectively. But the $\Delta T/\Delta t$ is always higher in value for higher flow rates of water but it too has a limitation for my fabricated design. Flow rate of 10lpm gave the best results and 15 lpm flow rate almost produced the same results. So higher the flow rate of liquid through the SWH better are the results but it too has some limitation.

The output obtained with 15lpm flow rate is not very satisfactory as a little decrease in temperature was observed for the same duration of heating. The reason for this can be the low intensity of sun's rays in the late afternoon. So as the ambient temperature falls down by a couple of degrees after 3:30 p: m it must have affected the solar water heating equipment. The ambient temperature and its relationship with the heating produced by solar water heater is not established in this paper.

CHAPTER-7

CONCLUSION

The hybrid solar heater collector thus fabricated was put to test under the sun while circulating water through it at different flow rates. The results obtained were satisfactory and the SWH efficiency went as high as 27.8 %. These types of solar water heaters can easily be used to heat pool water. A flow rate comparable to that of 15 lpm is best for heating. The heaters are to be used intermittently for heating a batch of water till 15-20 minutes until the efficiency drops down and then fresh water be circulated through it. A cycle like this would give us the maximum output in minimum time.

As far as swimming pool heating is concerned these type of unglazed solar collectors are the best as the pool water is always at a lower temperature than the heated surface of the collector. Solar pool covers made out of special kind of polymer can be used to cover the pool surface well, and reduce evaporative losses. This will add to the efficiency of the solar collectors.

More experiments can be carried out with the solar collector fabricated to know the ideal flow rate for obtaining the maximum efficiency of the collector. Dependence on the degree of heating with the ambient temperature couldn't also be carried out during this project which can be another research area.

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Site Resources:

- http://www.wbdg.org/resources/swheating.php
- http://www.instructables.com/id/DIY-Solar-Powered-Water-Heater-3-Steps/
- http://ecowanderer.wordpress.com/2009/12/18/diy-solar-powered-water-heater/
- http://www.builditsolar.com
- http://www.jc-solarhomes.com/how_to.htm
- http://apps1.eere.energy.gov/buildings/energyplus/cfm/weather_data2.cfm/
- http://solardat.uoregon.edu/index.html
- http://wikimapia.com
- http://googlemaps.com
- http://www.ngdc.noaa.gov/geomag/geomag.shtml
- http://www.ngdc.noaa.gov/geomagmodels/struts/calcDeclination

Software Resources:

- ❖ Google Earth & Wikimapia
- ❖ Google Sketch
- ❖ Solar 2
- ❖ Climate 5

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